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Self-reported exposure to hazards and mitigation strategies among oil and gas extraction workers in three U.S. states

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Abstract

Numerous health and safety hazards exist at U.S. onshore oil and gas extraction worksites. Higher fatal injury rates have been reported among drilling and servicing companies, which are more likely to employ workers in construction and extraction occupations, compared to operators that employ more workers in management and office and administrative support roles. However, there is little information describing the extent to which workers encounter these hazards, are provided hazard mitigation strategies by their employers, or use personal protective equipment (PPE). A cross-sectional survey of 472 U.S. oil and gas extraction workers was conducted to identify and characterize factors related to on-the-job fatalities, injuries, and illnesses and determine workers' health and safety concerns. Workers were employed by servicing companies (271/472, 57.4%), drilling contractors (106/472, 22.5%), and operators (95/472, 20.1%). The likelihood of contact with hazardous substances varied by substance and company type. Drilling and servicing employees had significantly higher odds of self-reported contact with pipe dope ($OR_{drilling}$ = 10.07, 95% CI: 1.74–63.64; $OR_{servicing}$ = 5.95, 95% CI: 2.18–18.34), diesel exhaust ($OR_{drilling}$ = 2.28, 95% CI: 1.15–5.05; $OR_{servicing}$ = 4.93, 95% CI: 2.73–10.32), and drilling mud ($OR_{drilling}$ = 24.36, 95% CI: 4.45–144.69; $OR_{servicing}$ = 3.48, 95% CI: 1.24–12.20), compared to operators.

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Disclosure statement

The authors declare no potential competing interests.

Institution and ethics approval and informed consent

The study protocol and survey were approved by the NIOSH Institutional Review Board (Protocol Number: 15-WSD-01XP) and the U.S. Office of Management and Budget (Protocol Number: 0920-1195). Researchers provided workers with the informed consent form and verbally explained the consent process. Assurances were provided that no personally identifiable information would be recorded or disclosed and that responses would be aggregated for presentation or publication.

Safety policies, programs, and trainings were commonly reported by workers, although substance-specific training (e.g., respirable crystalline silica hazards) was less common. Differences in self-reported employer PPE requirements and worker use of PPE when needed or required for safety highlight a need for novel strategies to improve the use of PPE. Overall, this study highlights differences in work conditions by company type and uncovers gaps in employer administrative controls and PPE use.

Keywords

Employer safety policies; hierarchy of controls; occupational exposure; occupational health; personal protective equipment

Introduction

The U.S. onshore oil and gas extraction (OGE) industry performs a variety of specialized tasks, and workers face many chemical and physical hazards. Health and safety practices may vary considerably between employers or subpopulations of workers due to factors including the existence and awareness of hazards, availability and adoption of effective mitigation strategies (e.g., hierarchy of controls), or costs and benefits of implementation. Fatality rates in the OGE industry have consistently exceeded those of US workers as a whole and have increased from 18.9 deaths per 100,000 workers in 2017 to 19.9 in 2018 and 22.0 in 2019 (BLS 2019, 2022a). Other common non-fatal injury and illness surveillance systems are poorly representative of OGE workers. OGE worker fatality rates also vary considerably by company type. A study found that in 2013 the fatality rates among drilling and servicing contractors exceeded operator fatality rates by more than four-fold (Mason et al. 2015). The OGE industry is led by operators (coded as 211 in the North American Industrial Classification System [NAICS]) that own and manage leased properties and set worksite standards for contractors. Operators hire contractors to provide support services for drilling or operating oil and gas wells and employ proportionally more workers in management and office and administrative support occupations compared to the companies they hire (BLS 2022b). Drilling contractors (NAICS 213111) drill oil and gas wells and perform well control activities. Servicing companies (NAICS 213112) provide specialized services for existing wells, such as well maintenance, cementing, or hydraulic fracturing. Contractors employ proportionally more workers in construction and extraction occupations (BLS 2022b). Little is known about the prevalence of established occupational hazards or if mitigation strategies vary by company type.

Hazardous substances such as hydrogen sulfide (H_2S), hydrocarbon gases and vapors (HGVs), diesel particulate matter (DPM), and respirable crystalline silica (RCS) have been reported at OGE worksites (Esswein et al. 2016). Pipe dope, a grease for connecting drill pipes, can contain lead, which is associated with hypertension and neurological or kidney damage (Khan 2011). Diesel engines powering heavy equipment produce DPM, a known carcinogen (OSHA 2013). Drilling fluids, which remove cuttings from the well bore and maintain formation pressure and stability, contain chemicals that can be neurotoxic and carcinogenic (OGP/IPIECA 2009). Quartz sand used during hydraulic fracturing (HF) to

stimulate well production produces RCS that can cause silicosis and other diseases (NIOSH 2002). Both the fracking fluid used to deliver sand to the fractures and flowback fluids released during HF operations can contain toxic, flammable, and corrosive chemicals (OSHA/NIOSH 2012; OSHA 2014). HGVs from production fluids like crude oil can be released during tank opening and gauging and can result in fires and explosions or oxygen-deficient atmospheres and cause respiratory, cardiovascular, and narcotic effects including sudden death (NIOSH 2016). OGE work environments may also contain physical hazards such as noise, radiation, and confined spaces (Harrison et al. 2016; Lawson et al. 2019; U.S. Environmental Protection Agency 2021). Injuries due to dropped objects and working from heights are common (Esswein et al. 2016). Implementation of the hierarchy of controls can reduce exposure risks to various hazards in OGE. The hierarchy of controls emphasizes elimination or substitution of the hazard as the most effective solution, followed by engineering and administrative controls, and personal protective equipment (PPE) as the last line of defense (NIOSH 2015).

Researchers conducted a survey, the first of its kind, to identify and characterize contributors to OGE work-related fatalities, injuries, and illnesses and determine OGE workers' health and safety concerns. This analysis focuses on a subset of questions related to specific occupational hazards and mitigation strategies and tests the hypotheses that worker demographics, workers' contact with hazardous substances and environments, employer administrative controls and PPE requirements, and workers' reported PPE use all differ by OGE company type.

Methods

Researchers conducted an in-person cross-sectional survey of a convenience sample of 500 OGE workers between October 2017 and February 2019. Recruitment was conducted with companies in Colorado, North Dakota, Oklahoma, Pennsylvania, Texas, and West Virginia to obtain variation in geographical location and target areas with substantial OGE activity. The study team used diverse recruitment methods (e.g., industry health and safety meetings, conferences, email, listservs, personal contacts) to identify companies and aimed to recruit the three OGE company types. Logistical considerations made it impossible to calculate company-level participation rates. Thirteen companies agreed to participate in Colorado, North Dakota, and Texas. Researchers and participating companies jointly identified specific locations where the survey was administered based on the accessibility of active well sites and the number of workers on the site. The National Institute for Occupational Safety and Health Institutional Review Board approved the study protocol and survey.

Survey design and pilot testing

The survey combined previously published questions (Sieber et al. 2014) with new OGE-specific questions developed in consultation with industrial hygienists with OGE expertise, industry health and safety professionals, and other subject matter experts. Table 1 shows survey questions relevant to this analysis.

Cognitive interviews and a pilot test of the draft survey were conducted with employees of an OGE company in Colorado to ensure the questions were understood as intended and

that sufficient response options were included to cover the variety of worker tasks and environments. Interviews focused primarily on the newly designed OGE-specific questions, including exposures and PPE. The pilot testing and interviews led to expansion and revision of the PPE questions. The pilot test survey took about 45 min to complete; some questions were removed or refined to shorten the survey to about 30 min. Because pilot testing showed that many workers' primary language was Spanish, all study materials were translated into Spanish and a Spanish-speaking researcher attended all survey administration unless informed that all participants would be proficient in English. Open-ended responses in Spanish were translated into English by a Spanish-speaking researcher.

Survey administration

Surveys were administered at well sites, monthly contractor meetings, and company field offices. All workers were invited to participate, including those who were employees of the participating employer and those who were employed as contractors. Workers completed the survey while being paid by their employer and in private areas, such as trailers or offices, away from their supervisors. Workers received gift cards in nominal amounts ($10 if on-duty and $30 if off-duty) for participation.

Workers were screened verbally to determine if they met the inclusion criteria required to take the survey, based on positive responses to two questions: "Have you worked in the oil and gas extraction industry for at least one month during the past year?" and "Do your work duties take you on to a wellsite at least two days per week or more?" Researchers provided workers with the informed consent form and verbally explained the consent process. Assurances were provided that no personally identifiable information would be recorded or disclosed and that responses would be aggregated for presentation or publication. Workers could take the survey on paper, a tablet, or verbally with responses recorded digitally by a researcher.

Data analysis

Descriptive and chi-square statistics were generated using R (Version 4.2.0, R Core Team, Vienna, Austria). A composite variable was created combining responses to questions on race and ethnicity: workers who responded "Yes" to the question, "Do you consider yourself to be Hispanic or Latino?" were classified as "Hispanic or Latino"; and workers who responded "No" and selected "White" alone for race were classified as "Non-Hispanic, White." Non-Hispanic workers who selected race values other than "White" (alone) were classified as "Non-Hispanic, Non-white." Workers who responded "Don't know" for Hispanic or Latino ethnicity or did not answer were set to missing.

Chi-square tests compared worker race and ethnicity using the composite variable described above, age group, years of experience, contact with six hazardous substances (i.e., drilling mud, fracking fluid, flowback fluid, crude oil, pipe dope, and diesel exhaust) and two work environments (i.e., opening tanks and use of sand), employer safety policies and programs, and requirements and use of seven types of PPE (i.e., hardhats, hearing protection, gloves, flame-resistant clothing, fall protection equipment, multi-gas monitors, and respirators) by company type. A Kruskal–Wallis test compared the median age across company types.

Workers responding “Yes” to the question, “Is sand used at your current worksite, such as for hydraulic fracturing?” were compared with workers responding “No” and “Don’t know.” Workers responding “Always” wearing PPE when needed or required for safety were compared with those responding “Most of the time,” “Some of the time,” and “Never.” Workers responding “Not needed for my job” were excluded from the analysis of this question.

Separate logistic regression models analyzed the relationships between contact with each hazard and company type. Final models incorporated adjustment for age and race and ethnicity if bivariate analysis of the relationship between each substance and predictor was significant at $p < 0.10$ and if overall model fit improved when including the additional predictor (i.e., Akaike’s information criterion, AIC). After consultation with subject matter experts, operator employees were hypothesized to be least likely to encounter hazardous substances and served as the reference category for all adjusted odds ratios. Through post hoc analyses, it was discovered that survey location was confounding the relationship between company type and contact, so the location was added as a random effect to all final models.

Results

Of the 528 OGE workers recruited to participate, 500 workers completed the survey, with a response rate of 94.7%. Two respondents were determined ineligible and excluded from the analysis because they reported less than one month of experience. A total of 472 respondents who selected “operator,” “servicing company,” or “drilling contractor” as their company type were included in this analysis, after removing 26 respondents who selected “other” as their company type or did not respond.

Worker demographics and company type

Respondents were mostly male (n = 458, 97.0%). Over half (57.4%) worked for servicing companies, 22.5% for drilling contractors, and 20.1% for operators (Table 2). About one-third (35.6%) of respondents identified as Hispanic or Latino. Servicing companies had the highest proportions of Hispanic or Latino employees (45.7%), compared to 10.6% of operator employees ($p < 0.001$). There were no statistically significant differences by company type for median age, age group, or years of oilfield experience. There were no statistically significant differences by race and ethnicity for age or years of experience (Supplementary Table 1). A variable to measure the language a respondent used for the survey may have been misclassified in up to three cases, resulting in between 50 and 53 respondents who completed the survey in Spanish (data not shown).

Self-reported contact with hazardous substances and environments

Self-reported contact with hazardous substances and work environments differed by company type (Table 3). The odds of contact with pipe dope were 10 times greater among drilling employees (OR = 10.07, 95% CI: 1.74–63.64) and six times greater among servicing employees (OR = 5.95, 95% CI: 2.18–18.34) compared to operator employees. Drilling and servicing employees also had significantly higher odds of contact with diesel exhaust

($OR_{drilling}$ = 4.93, 95% CI: 2.73–10.32; $OR_{servicing}$ = 2.28, 95% CI: 1.15–5.05). The odds of contact with drilling mud were over 24 times greater among drilling employees (OR = 24.36, 95% CI: 4.45–144.69) and three times greater among servicing employees (OR = 3.48, 95% CI: 1.24–12.20), compared to operators.

Respondents were also asked to rate their level of concern about contact with any of the substances included in this study (data not shown). Of the 454 workers who answered this question, 49.8% reported no concern and 7.7% were very concerned. When asked what chemical hazards or substances they were most concerned about, respondents most commonly reported caustic soda (n = 28), H_2S (n = 22), and acid (n = 20).

Although not significant, drilling employees had higher odds of opening tank hatches or working around open tanks compared to operators (OR = 1.22, 95% CI: 0.33, 5.06).

Inclusion of race and ethnicity in the regression models to improve model fit revealed greater odds of contact with select substances among Hispanic or Latino and non-Hispanic non-White workers compared to non-Hispanic White workers, after accounting for company type (Supplementary Table 2). The odds of contact with pipe dope or drilling mud were greater among Hispanic or Latino (OR = 2.03, 95% CI: 0.93–4.68; OR = 1.40, 95% CI: 0.70–2.80) and non-Hispanic non-White workers (OR = 2.02, 95% CI: 0.59–9.58; OR = 1.86, 95% CI: 0.60–5.70). Non-Hispanic non-White workers also had greater odds of sand at their worksites (OR = 1.88, 95% CI: 0.73–4.71). Among the final models that included age, odds ratios were close to 1 ($OR_{pipe\ dope}$ = 0.98, 95% CI: 0.96–1.01; OR_{diesel} = 0.98, 95% CI: 0.96–1.00; OR_{mud} = 0.99, 95% CI: 0.97–1.02; $OR_{tank\ opening}$ = 0.97, 95% CI: 0.95–0.99).

Employer policies, programs, and trainings

Over 90% of respondents reported that their employer had workplace safety programs, policies, rules, or guidelines and daily task-specific job hazard or safety analysis (Table 4). Proportions of respondents whose employers had new worker programs such as mentoring differed significantly by company type ($p < 0.001$). Fewer than half of respondents reported that their companies had safety awards or incentives (42.7%), with the highest proportion among operator employees (54.3%; $p = 0.007$). There were significant differences by company type for respondents who reported receiving formal classroom training through SafeLandUSA or IADC RigPass ($p < 0.001$), with the lowest percentage among operators (45.3%). Among the 90 respondents reporting sand at their current worksite, 69.8% reported they had received training or information on silica exposure hazards and 74.3% reported that silica exposure controls were used at their current company.

Overall, 98.1% of respondents reported that they were trained well enough to do their job safely (data not shown). Almost all respondents had received training or information in the past year on topics such as hazard recognition and assessment (96.6%), hazard communication (96.4%), safety data sheets (96.6%), use of PPE (97.4%), work in confined spaces (87.1%), and job hazard analysis (98.9%).

PPE

PPE requirements and use varied significantly by company type (Table 5). Nearly all respondents (99.8%) reported their employer required hardhats for their job tasks, but the proportions reporting always wearing them when needed or required for safety differed significantly by company type ($p < 0.001$), with the lowest compliance among servicing employees (86.4%). Nearly all drilling employees (99.1%) reported fall protection equipment requirements, compared to 86.3% of servicing employees and 67.0% of operator employees ($p < 0.001$). Overall, 73.4% reported always wearing fall protection equipment when needed or required, with the highest proportions among drilling employees (84.5%, $p = 0.012$).

Nearly all respondents (97%) reported their employer required flame-resistant (FR) clothing for performing their job tasks, with no variation by company type. Similarly, there was little variation in the use of FR clothing.

Over 95% of drilling or servicing employees reported glove requirements, compared to 73.7% of operator employees ($p < 0.001$). Lower percentages of respondents always wore gloves when needed or required: 79.5% of servicing employees, compared to 65.1% of drilling employees and 60.2% of operators ($p < 0.001$).

Nearly all drilling employees (96.2%) reported a respirator requirement for any of their job tasks, compared to 73.4% of operator employees and 61.2% of servicing employees ($p < 0.001$). Over three-quarters (76.3%) of drilling employees always wore a respirator when needed or required, compared to those who worked for an operator (64.3%) or servicing company (54.0%) ($p < 0.001$). Additionally, 11.8% percent of all respondents reported never wearing a respirator when needed or required for safety (data not shown).

The proportion of respondents reporting employer requirements for hearing protection varied significantly by company type ($p < 0.001$), with the lowest percentages among servicing (67.2%) and operator (70.5%) employees. Hearing protection was the least commonly worn PPE. Fewer than 40% of respondents always wore hearing protection when needed or required, with the lowest percentage observed among servicing employees (29.9%, $p < 0.001$).

Discussion

Summary of key findings

The study confirmed the hypotheses that worker demographics, self-reported contact with hazardous substances and environments, employer administrative controls, and PPE requirements and reported use differ significantly by company type. The odds of self-reported contact with hazardous substances varied by company type, after accounting for employee demographics. The proportions of respondents reporting employer policies, programs, and trainings also differed by company type, as did PPE requirements and reported use.

Worker demographics and company type

The distribution of company type among survey respondents was fairly consistent with national estimates. In 2019, 57.1% of OGE workers worked for servicing companies, 12.8% for drilling contractors, and 30.0% for operators (BLS 2019). The survey population consisted of a smaller proportion of operators (20.1%) and a larger proportion of drilling contractors (22.5%).

The 50 workers who completed the survey in Spanish demonstrate that OGE companies with higher proportions of Spanish-speaking employees should offer training in the appropriate language to ensure all workers are aware of occupational hazards, mitigation strategies, and legal protections.

The employment structure at an OGE well site typically includes multiple inter-related employers, consistent with the concept of a “fissured workplace” (Weil 2017). Specialized small companies compete for contract work awarded by a larger corporate entity that manages roles, responsibilities, and safety and quality standards for a single worksite through sub-contracts or other mechanisms. Each specialized task performed by a company presents its own set of unique hazards, exposures, and necessary controls. Thus, the heterogeneity of job tasks among servicing companies may have biased reported odds ratios toward the null. For example, contact with crude oil by specialized servicing company employees may be more common than reported here. Future studies concerned with particular hazards should selectively recruit servicing companies according to their specialty areas. However, the three NAICS-based categories are representative of the OGE industry and were a meaningful starting point for this analysis.

Self-reported contact with hazardous substances and environments

The survey identifies differences in self-reported contact with hazardous substances by company type that are believed to be representative of the types of tasks performed by servicing companies, drilling contractors, and operators. Employees of drilling contractors and servicing companies had greater odds of contact with pipe dope and drilling mud, consistent with the activities performed at drilling sites. One study suggested that drilling contractors consider using lead-free pipe dope, provide facilities to change out of contaminated clothing, and mandate proper PPE use to reduce workplace and take-home lead exposures (Khan 2011). The association between contact with pipe dope and servicing company employment suggests that lead exposure prevention strategies may also be beneficial for servicing companies. Facilities to change contaminated clothes and efforts to increase PPE use may help reduce contact with other substances drilling and servicing workers encounter, such as drilling mud.

Drilling and servicing employees also had greater odds of contact with diesel exhaust. Concentrations of DPM aerosols are reported in industries using diesel-powered equipment and older diesel engines (Pronk et al. 2009; Vermeulen and Portengen 2016). One OGE field study concluded that while all workers onsite had risks for exposure to DPM, the highest risks were at HF sites, where numerous diesel engines are the point source emissions for DPM (Esswein et al. 2018). Results from this survey provide evidence that contact

with diesel exhaust can be widespread in the industry, particularly among well-servicing workers during HF. Upgrading older equipment and applying additional engineering and administrative controls (e.g., exhaust stack extensions, evaluation of emission source strengths and wind patterns, limiting time spent in locations with exposure risks to DPM) may help protect workers from DPM exposures (Esswein et al. 2018).

Studies report that OGE workers working around tanks and with production and flowback process fluids have exposure risks for HGVs that have resulted in deaths, but it is unclear how many workers actually perform these tasks (Esswein et al. 2014; Harrison et al. 2016). Drilling employees had greater odds of opening tanks, compared to operators. To decrease exposure risks associated with production and flowback tank emissions, companies can incorporate engineering controls (e.g., remote or automatic tank gauging, blowdown valves, tank sampling taps), work upwind, and require and enforce PPE use (NIOSH 2016). Additional exposure assessment research is needed to confirm which OGE occupations have increased risks for exposures to specific hazardous substances to effectively apply the hierarchy of controls.

The statistical modeling results provide suggestive but inconclusive data that OGE workers from racial and ethnic minority groups are more likely to report contact with some substances, regardless of the type of company they work for. Relative to non-Hispanic White respondents, Hispanic or Latino respondents, and non-Hispanic, non-White respondents had elevated but non-significant odds ratios for contact with pipe dope and drilling mud. Non-Hispanic, non-White respondents also had greater odds of sand used at the worksite. Occupational health disparities research within and across industries indicate that Hispanic workers may be more likely to face occupational health and safety risks and have higher rates of fatal work-related injuries than non-Hispanic workers (Cierpich et al. 2008; Arcury-Quandt et al. 2011; Eggerth et al. 2019). Determining whether similar dynamics exist within OGE requires additional research. Although age and years of experience did not appear to be significantly different by race and ethnicity, there were relatively more Hispanic or Latino employees among servicing companies and drilling contractors compared to operators, which may further explain the higher odds of contact with certain substances.

Regardless of company type, increasing worker age was associated with lower odds of opening tanks and contact with pipe dope, diesel, and drilling mud. These data would be explained if, due to seniority or advancement into less manual roles, older workers performed this task less often than younger workers.

Although the majority of survey respondents reported contact with at least one hazardous substance, almost half were not concerned and less than 10% were very concerned. This lack of reported concern among some respondents may be due to a myriad of explanations, including an absence of immediate injuries requiring treatment, a lack of hazard or risk awareness for exposures having latent consequences, or a feeling of adequate protection by engineering or administrative controls or PPE use. The survey respondents who reported being very concerned about contact with hazardous substances may work more closely with hazardous substances during their daily work activities or have increased knowledge or experience with the health effects associated with some of these substances.

Employer policies, programs, and trainings

Nearly all respondents reported workplace safety programs, policies, rules, or guidelines and daily task-specific job hazard or safety analysis. New worker programs such as mentoring were most common among drilling and servicing employees, which may be due to high turnover among contractors and a younger workforce compared to operators. Safety awards or incentives were reported most frequently among operator employees. Larger companies may have greater access to resources such as health and safety professionals who can develop such programs (Esswein et al. 2016). All companies should consider the potential for unintended consequences from safety awards or incentives, such as intentional underreporting of injuries (Maslen and Hopkins 2014).

Less than three-quarters of respondents reporting sand at their worksites reported controls to limit exposure to silica dust. The extent to which administrative controls and PPE are currently being used on HF sites is unknown (Esswein et al. 2019). The OSHA Silica Standard establishing a new permissible exposure limit for RCS and requiring employers to conduct exposure assessments to understand RCS risks, provide respirators, and implement controls to protect workers from exposures became enforceable in June 2018, midway through the survey collection period (Respirable Crystalline Silica, 29 CFR 1910.1053). Additionally, OSHA mandated HF operations to implement engineering controls to limit RCS exposures by June 2021. This analysis provides a snapshot of the prevalence of RCS controls from workers' perspectives before the enactment of this new standard. Additional research is needed to determine the prevalence of RCS controls at OGE worksites, specifically during HF, and to evaluate the impacts of the new standard.

This study suggests that gaps in training may exist in the industry. For example, only 70% of respondents reporting sand at their worksites reported training or information on silica dust hazards. A similar proportion received SafeLandUSA or IADC RigPass Orientation, with operator employees least likely to have received these. This result is not surprising, as these trainings were developed as standardized worker safety orientations for contractors (Esswein et al. 2016); however, both operators and contractors could benefit from these trainings. It is also important to note that the questions asking about silica training and SafeLandUSA or IADC RigPass Orientation did not specify whether these trainings were provided by the respondent's current company. Although turnover between companies is common in the OGE industry, switching between company types is less common. Training is the responsibility of the employer and may be influenced by internal drivers such as commitments to federal regulations and health and safety beliefs (Henley et al. 2011). It is also likely that if contractors are working for large operators, the operator may stipulate separate, company-specific training requirements for contractors on their sites (Shell 2022).

PPE

For several types of PPE, whether respondents' employers required it for their job tasks and whether they always wore it differed significantly by company type. These differences might reflect variations in the kind of work done by each company type and the work tasks performed by individual respondents. Drilling contractor employees were most likely to report that their employer required almost all of the seven types of PPE for their job

tasks. This finding is not surprising given that drilling operations can involve contact with numerous hazardous substances (OGP/IPIECA 2009).

Employer requirements and worker compliance are highest for FR clothing compared to all other PPE apart from hardhats and may be potential indicators of success resulting from OSHA's efforts to clarify enforcement of FR clothing in OGE. OSHA typically relies on the general industry standard for enforcement of PPE as OGE lacks a specific industry standard; however, a 2010 memorandum provided the specific interpretation that failure to provide and use FR clothing in OGE is a violation of the general industry standard (OSHA 2010). Additional interpretations with specific guidance for OGE may yield positive compliance for other administrative and PPE controls.

For some PPE types, this study revealed substantial differences between employer PPE requirements and respondents' self-reported compliance with those requirements. For servicing company employees, the difference between the percentage required and the percentage always used was more than 15 percentage points for fall protection, gloves, multi-gas monitors, and hearing protection. For example, 67.2% of servicing employees reported that their employer required hearing protection for their job tasks, but only 29.9% reported always wearing it when needed or required. Previous research based on audiograms showed a 27.3% prevalence of hearing loss among operator employees and 13.1% among servicing employees, with both groups at significantly higher risk than a reference cohort (Lawson et al. 2019). The findings of this study reinforce the need for employer requirements for hearing protection, especially as some aspects of OGE are exempt from parts of the OSHA noise standard requiring employer-provided hearing conversation programs for noise-exposed workers (Occupational Noise Exposure, 29 CFR 1910.95). Employers are responsible for facilitating the procurement of hearing protection devices and other applicable PPE, providing training in the proper use and care of devices, and enforcing the use of PPE when required for safety (NIOSH 1996).

Despite nearly universal glove-use requirements reported by drilling and servicing employees and OSHA regulation that mandates employers require hand protection when employees' hands are exposed to hazards, much lower proportions of workers reported they always wore gloves when needed or required for safety (Hand Protection, 29 CFR 1910.138). The findings raise questions about whether glove policies are adequately communicated or enforced and whether employees were engaged in policy development. Additional research is needed to evaluate the fit and function of the gloves used in different OGE occupations. Other OGE studies focused on motor vehicle safety have reported similar gaps between employer policy and worker compliance regarding seat belts, mobile phone use, and drowsy driving (Rothe 2008; Ramirez-Cardenas et al. 2021).

Depending on the type of respiratory protection and proper use, respirators can protect OGE workers from exposure to HGVs, H_2S, RCS, DPM, and oxygen deficiency. In this study, while most drilling workers' employers required respirators for job tasks, much lower percentages always used them when needed or required. Percentages of the operator and servicing employees whose jobs required a respirator and who always used one were lower than for drilling employees. Use of sand is common in servicing companies conducting HF

and risks for worker exposures to RCS is documented (Esswein et al. 2013). Although other RCS controls have been proposed, continued use of respirators is recommended until these controls have been proven effective (Esswein et al. 2019). Respirators, along with gloves, multi-gas monitors, and FR clothing, are also critical for protecting OGE workers from exposure to HGVs, fires, and explosions while opening or gauging tanks (NIOSH 2016).

Strengths and limitations

This was the first national survey of U.S. onshore OGE workers that examined self-reported contact with hazardous substances and environments; employer safety policies, programs, and trainings; and employer requirements for and employee use of PPE.

There are limitations to this study. Workers reported contact with hazardous substances but did not report the frequency or severity of contact with each substance. Respondents' understanding of "contact" may have varied as this wasn't explicitly defined. Some workers may not have reported contact with a substance if the contact was imperceptible or they did not believe their contact resulted in an acute effect that may be an immediate cause for concern. Residual confounding may have affected modeling results if important confounders between company type and contact with hazards were unaccounted for in the models. Despite pilot testing of the survey, additional questions may have been misinterpreted by the respondents. Further research is needed to validate survey questions unique to the OGE industry. Researchers were unable to confirm with host companies if the worker-reported administrative controls are actually in place.

The sampling strategy was selected because other sampling strategies (e.g., population-based sampling) would have been much more difficult, if not impossible. Access to well sites is granted by operators and therefore only possible through strong industry partnerships. High turnover and low unionization rates make identifying OGE workers through other means very difficult. The sampling strategy may have limited or biased our findings in various ways. The convenience sample overrepresented Hispanic workers compared to the U.S. OGE industry, likely due to higher participation among Texas-based companies. Their experiences may differ, on average, from non-Hispanic workers. Many exposure risks for OGE workers can have latent effects from chronic exposures (e.g., RCS, lead, benzene, noise, DPM). The study's cross-sectional design was not intended to detect such effects. Further, participating companies may have had greater interest and commitment to workplace safety compared to companies that did not choose to participate. Response bias may have resulted from respondents completing the survey on job sites. Due to the self-report nature of the survey, recall or reporting bias may have impacted the accuracy of results. Although respondents were told that their responses would be anonymous and aggregated, reluctance to report undesirable behaviors may also have introduced bias. Low percentages of reported use for some PPE provides some reassurance that workers responded honestly. This analysis did not evaluate workers' self-reported job titles due to variability across companies that presented challenges common in the collection of occupation data. The range of servicing activities was also not evaluated as workers did not specify company details beyond company type. Additional research is needed to understand occupational hazards and risks related to specific servicing activities.

Conclusions

The presence of hazardous substances and environments is widely reported among OGE workers, but hazards and risks vary by company type. Although some employer PPE requirements are almost universal (e.g., multi-gas monitors), some workers did not report always wearing PPE when needed or required for safety. PPE requirements and use vary depending on specific job tasks, which were not measured in this survey. OSHA standard interpretations and employee engagement in the design and use of PPE may play roles in greater PPE use. Efforts to prioritize engineering and administrative controls will help protect OGE workers from chemical hazards. Additional research is needed to better understand the association of hazards with specific OGE occupations to further target controls and recommendations to specialized companies. Operators serve an important role in identifying hazards, promoting the most effective controls, and setting health and safety standards among their contractors.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, KW, upon reasonable request.

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Table 1.

Questions from survey instrument related to hazards and mitigation strategies and implemented with 472 oil and gas extraction workers in three U.S. states.

Question	Allowable responses
Company information	
What type of company do you work for?[a]	• Drilling contractor • Servicing company • Operator • Other (please specify) • Don't know
Hazardous substances and environments	
Please list if you come in contact with the following products. **a.** Drilling mud **b.** Fracking fluid **c.** Flowback fluids **d.** Crude oil **e.** Pipe dope **f.** Diesel exhaust **g.** Other: _____	• Yes • No *Note: A response was selected for each product.*
Rate your level of concern about contact with these products.	• No concern • Slightly concerned • Somewhat concerned • Very concerned
What chemical hazards or substances are you most concerned about?	Open-ended response
At work, do you open tank hatches or work around open tanks at least twice a week or more?	• Yes • No

Question	Allowable responses
Is sand used at your current worksite, such as for hydraulic fracturing?	• Yes • No • Don't know
Employer policies, programs, and trainings	
Does your company have a safety program, written policies, rules, or guidelines regarding workplace safety?[b]	• Yes • No Don't know
Does your company conduct daily task-specific Job Hazard Analysis/Job Safety Analysis or something similar?	• Yes • No • Don't know
Does your company have a program for workers who are new to the oilfield, such as mentoring?	• Yes • No • Don't know
Does your company offer safety awards/incentives?[b]	• Yes • No • Don't know
Have you ever received formal classroom training in SafelandUSA or IADC RigPass Orientation?	• Yes, 0–12 months ago • Yes, 12+ months ago • No • Don't know
Have you received training or information on the hazards to exposure to silica dust from sand?	• Yes • No • Don't know *Note: Only answered by those who selected "Yes" to the previous question asking if sand is used at current worksite.*
Has your current company implemented controls to limit your exposure to silica dust, such as requiring respirators while working around sand, using equipment that limits dust generation, or using policy or procedures to limit number of times or duration you are exposed to silica dust?	• Yes • No • Don't know

Question	Allowable responses
	Note: Only answered by those who selected "Yes" to the previous question asking if sand is used at current worksite.
Do you think you were trained well enough to do your job safely?	• Yes • No • Don't know
In the past year, have you received training or information related to any of the following topics? • Hazard recognition and assessment • Hazard communication • Safety data sheets • Use of personal protective equipment • Confined space	• Yes • No • Don't know *Note: A response was selected for each topic.*
Personal Protective Equipment (PPE)	
Does your employer require you to wear _____ to do any of your job tasks?[c] • Hardhat • Hearing protection • Gloves • Flame resistant (FR) clothing • Fall protection equipment • Multi gas monitor (CO, O_2, LEL, H_2S) • Respirator	• Yes • No *Note: A response was selected for each type of PPE.*
How often do you wear your _____ when it is needed or required for safety?[c] • Hardhat • Hearing protection • Gloves • Flame resistant (FR) clothing • Fall protection equipment • Multi gas monitor (CO, O_2, LEL, H_2S) • Respirator	• Not needed for my job • Never • Some of the time • Most of the time • Always *Note: A response was selected for each type of PPE.*

[a]Allowable responses based on NAICS.

[b]Previously published question in the National Survey of U.S. Long-Haul Truck Driver Health and Injury (Sieber et al. 2014).

[c]Revised based on pilot testing.

Table 2.

Oil and gas extraction worker demographic characteristics, by company type (n = 472).

	Total n (%)[a]	Operator n (%)[a]	Servicing company n (%)[a]	Drilling contractor n (%)[a]	*p*-value
All workers	472 (100.0)	95 (20.1)	271 (57.4)	106 (22.5)	–
Race/Ethnicity					<0.001[b]
Hispanic or Latino	166 (35.6)	10 (10.6)	122 (45.7)	34 (32.4)	
Non-Hispanic, White	266 (57.1)	77 (81.9)	125 (46.8)	64 (61.0)	
Non-Hispanic, Non-White	34 (7.3)	7 (7.4)	20 (7.5)	7 (6.7)	
Missing	6	Too few records to report			
Age (median years)	34.0	35.0	34.0	34.0	0.091[c]
Age group					0.091[b]
Less than 35 years	241 (51.3)	44 (46.3)	139 (51.5)	58 (55.2)	
35 to 45 years	127 (27.0)	26 (27.4)	67 (24.8)	34 (32.4)	
More than 45 years	102 (21.7)	25 (26.3)	64 (23.7)	13 (12.4)	
Missing	2	Too few records to report			
Years of oilfield experience					0.113[b]
Less than 5 years	139 (29.6)	21 (22.1)	77 (28.6)	41 (39.0)	
5 to 10 years	152 (32.4)	35 (36.8)	86 (32.0)	31 (29.5)	
More than 10 years	178 (38.0)	39 (41.1)	106 (39.4)	33 (31.4)	
Missing	3	Too few records to report			

[a]Missing responses were removed from the denominator for percent calculations.

[b]Chi-square test.

[c]Kruskal-Wallis test.

Table 3.

Self-reported contact with hazardous substances and environments among oil and gas extraction workers, by company type (n=472).

	Total n (%)[a]	Operator n (%)[a]	Servicing company			Drilling contractor		
			n (%)[a]	Odds ratio[b] (95% confidence interval)	*p*-value[c]	n (%)[a]	Odds ratio[b] (95% confidence interval)	*p*-value[c]
Contact with hazardous substances								
Pipe dope	343 (81.7)	53 (64.6)	193 (82.1)	5.95 (2.18–18.34)[d]	<0.001	97 (94.2)	10.07 (1.74–63.64)[d]	0.009
Diesel exhaust	311 (77.6)	42 (55.3)	197 (86.0)	4.93 (2.73–10.32)[e]	<0.001	72 (75.0)	2.28 (1.15–5.05)[e]	0.015
Crude oil	231 (59.5)	71 (78.9)	135 (63.1)	2.05 (0.80–5.41)	0.136	25 (29.8)	0.73 (0.18–3.26)	0.660
Drilling mud	178 (49.9)	10 (14.5)	70 (38.0)	3.48 (1.24–12.20)[d]	0.026	98 (94.2)	24.36 (4.45–144.69)[d]	<0.001
Flowback fluids	167 (45.6)	43 (53.1)	105 (51.2)	1.17 (0.59–2.46)	0.668	19 (23.8)	0.55 (0.18–2.20)	0.349
Fracking fluid	97 (28.2)	21 (27.6)	69 (36.5)	1.58 (0.75–3.49)	0.229	7 (8.9)	0.39 (0.10–1.86)	0.182
Hazardous work environments								
Open tank hatches or work around open tanks at least twice a week	165 (36.3)	40 (42.6)	73 (28.6)	0.35 (0.14–0.82)[e]	0.016	52 (49.5)	1.22 (0.33–5.06)[e]	0.774
Sand used at worksite	90 (20.0)	40 (43.0)	49 (19.4)	0.27 (0.11–0.58)[f]	0.001		Too few records to report	

[a] Missing responses were removed from the denominator for percent calculations. Logistic regression models excluded records missing data on age (n=2) or race/ethnicity (n=6) when one or both variables were included in the model.

[b] Reference category: operators. Random effect: survey location.

[c] Multiple logistic regression.

[d] Adjusted for age and race/ethnicity.

[e] Adjusted for age.

[f] Adjusted for race/ethnicity.

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Table 4.

The presence of select employer policies[a], programs, and trainings, as reported by oil and gas extraction workers, by company type (n = 472).

	Total n (%)[b]	Operator n (%)[b]	Servicing company n (%)[b]	Drilling contractor n (%)[b]	*p*-value
Workplace safety program, written policies, rules, guidelines	458 (97.7)	94 (100)	259 (96.3)	105 (99.1)	0.143[c]
Daily job hazard/safety analysis	438 (93.6)	90 (95.7)	244 (91.0)	104 (98.1)	0.066[c]
New worker program	397 (85.0)	67 (71.3)	225 (84.3)	105 (99.1)	<0.001
Safety awards/incentives	200 (42.7)	51 (54.3)	116 (43.3)	33 (31.1)	0.007
SafeLandUSA or IADC RigPass Orientation[d]	322 (69.0)	43 (45.3)	200 (75.2)	79 (74.5)	<0.001
Training or information on hazards of exposure to silica dust from sand (n = 90)[e]	60 (69.8)	27 (69.2)	32 (69.6)	Too few records to report	0.803[c]
Controls to limit exposure to silica dust, such as PPE, equipment, policies, or procedures (n = 90)[e]	52 (74.3)	26 (89.7)	25 (62.5)	Too few records to report	0.033[c]

[a]Responses to indicate the existence of a given policies/program included “Yes,” “No,” and “Don’t know.” The values shown reflect workers who selected “Yes” and proportions are based on those who responded to the question. Chi-square tests compared all three responses by company type.

[b]Missing responses were removed from the denominator for percent calculations.

[c]Chi-square result may be unreliable due to expected cell counts of less than 5.

[d]The values shown reflect workers who indicated having received these trainings by selecting either “Yes, 0–12 months ago,” or “Yes, 12 months ago.” Chi-square tests combined these two responses and compared with “No” and “Don’t know” across company type.

[e]Of the 90 respondents who reported sand was used at their current worksites.

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Table 5.

Employer PPE requirements and how often always[a] wearing when needed or required for safety, as reported by oil and gas extraction workers, by company type (n = 472).

	Total n (%)[b]	Operator n (%)[b]	Servicing company n (%)[b]	Drilling contractor n (%)[b]	*p*-value[c]
Hardhat					
Required by employer	464 (99.8)	95 (100)	263 (99.6)	106 (100)	0.683[d]
Always worn	422 (90.9)	90 (95.7)	228 (86.4)	104 (98.1)	<0.001
Fall protection equipment					
Required by employer	395 (85.3)	63 (67.0)	227 (86.3)	105 (99.1)	<0.001
Always worn	289 (73.4)	36 (69.2)	166 (69.5)	87 (84.5)	0.012
Flame resistant (FR) clothing					
Required by employer	452 (97.0)	95 (100)	251 (94.7)	106 (100)	0.004[d]
Always worn	425 (93.2)	88 (95.7)	233 (90.3)	104 (98.1)	0.016
Gloves					
Required by employer	429 (92.1)	70 (73.7)	256 (96.6)	103 (97.2)	<0.001
Always worn	331 (72.4)	53 (60.2)	209 (79.5)	69 (65.1)	<0.001
Multi-gas monitor (CO, O_2, LEL, H_2S)					
Required by employer	429 (93.3)	95 (100)	233 (89.6)	101 (96.2)	0.001
Always worn	339 (77.6)	71 (76.3)	178 (74.2)	90 (86.5)	0.039
Respirator					
Required by employer	329 (71.7)	69 (73.4)	159 (61.2)	101 (96.2)	<0.001
Always worn	226 (61.9)	45 (64.3)	107 (54.0)	74 (76.3)	<0.001
Hearing protection					
Required by employer	339 (72.7)	67 (70.5)	178 (67.2)	94 (88.7)	<0.001
Always worn	171 (39.8)	42 (55.3)	76 (29.9)	53 (53.0)	<0.001

[a]Participants were asked how often they wore each PPE when it is needed or required for safety. The values shown include those who responded, “Always.” Additional responses, “Most of the time,” “Some of the time,” and “Never” were combined and compared with those who responded “Always” for chi-square tests.

[b]Missing responses were removed from the denominator for percent calculations.

[c]Chi-square test.

[d] Chi-square result may be unreliable due to expected cell counts of less than 5.